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(11) **EP 0 936 665 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:  
18.08.1999 Bulletin 1999/33

(51) Int Cl.<sup>6</sup>: **H01L 21/762**

(21) Application number: **99102632.9**

(22) Date of filing: **11.02.1999**

(84) Designated Contracting States:  
**AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU  
MC NL PT SE**  
Designated Extension States:  
**AL LT LV MK RO SI**

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(30) Priority: **12.02.1998 JP 2999898**

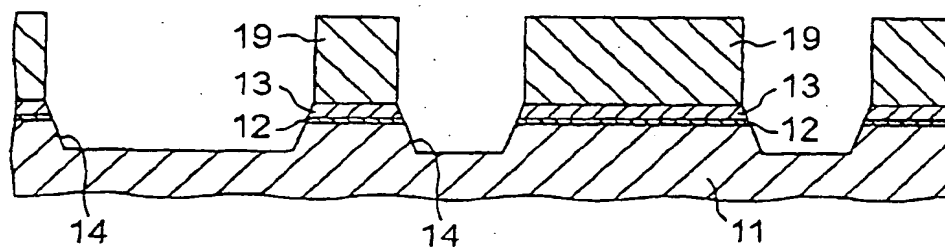
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(54) **Semiconductor device having a shallow isolation trench and fabrication process**

(57) A method for forming a semiconductor device having an isolation trench (14) for separation of element regions includes the steps of forming a pad oxide film (12) and a silicon nitride film (13) on a silicon substrate (11), forming an isolation trench (14) by using the silicon nitride film as a mask, forming consecutively a thermal oxide film (15), CVD oxide film (16) and a bias oxide film

(17) in the isolation trench (14), removing the films above a specified level of the silicon substrate (11) to leave the isolation trench (14) filled with oxide films (15, 16 and 17). The bias oxide film (17) is formed by a high-density plasma CVD technique. The silicon surface is protected by the CVD oxide film (16) against the plasma damage during the high-density CVD step, thereby obtaining excellent characteristics of transistors.



**FIG. 5A**

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## Description

### BACKGROUND OF THE INVENTION

#### (a) Field of the Invention

[0001] The present invention relates to a semiconductor device having a shallow isolation trench and, more particularly, to a technique for forming an shallow isolation trench for separation between device elements in a LSI.

#### (b) Description of the Related Art

[0002] In a shallow trench isolation (STI) technique, element regions for forming device elements such as transistors are isolated from one another by using a shallow trench. In a dynamic random access memory (DRAM) using the STI technique, for example, the dimensions of the shallow trench has been increasingly reduced with the reduction of the device elements and improvement of the fabrication technique for the LSI.

[0003] Figs. 1 and 2 show an example of a semiconductor device in fabrication steps thereof at a location of a shallow isolation trench. In Fig. 1, a silicon oxide film (or pad oxide film) 32 having a thickness of about 200 angstroms and a mask silicon nitride (SiN) film 33 having a thickness of 0.15 micrometers ( $\mu\text{m}$ ) are consecutively formed on a silicon substrate 31, followed by formation of a photoresist film (not shown) having a mask pattern. Subsequently, the mask nitride film 33 and the pad oxide film 32 are selectively etched by using the photoresist film as a mask to expose a portion of the silicon substrate 31, followed by dry etching of the silicon substrate 31 for a specified depth to form a shallow isolation trench 34 for isolation of device elements.

[0004] Thereafter, a silicon oxide film 35 having a specified thickness is formed by a low-pressure chemical vapor deposition (LPCVD) within the isolation trench 34 and in the vicinity thereof, followed by chemical-mechanical polishing (CMP) of portions of the CVD oxide film 35 and the mask nitride film 33 disposed above a dotted line "A". Subsequently, the CVD oxide film 35, the mask nitride film 33 and the thermal oxide film 32 are subjected to a wet etching for removing the portions of the CVD oxide film 35, the mask nitride film 33 and the thermal oxide film 32 disposed above a dotted line "B" to expose the surface of the silicon substrate 11 and to leave portions of the CVD oxide film 35 and the thermal oxide film 32 within the shallow isolation trench 34.

[0005] Thereafter, as shown in Fig. 2, a gate oxide film 37 is formed on the exposed surface of the silicon substrate 11, followed by another CVD step to form a polycrystalline silicon (polysilicon) film 38 on the CVD oxide film 35 and the gate oxide film 37. An amorphous silicon film may be formed instead of the polysilicon film 38.

[0006] The current fabrication technique for the semiconductor devices enables to form a shallow isolation

trench having a width of about 0.5  $\mu\text{m}$ . However, if the width of the isolation trench to be formed in a LSI is less than 0.4  $\mu\text{m}$ , such as in the case of 0.25  $\mu\text{m}$  design rule, the LSI thus fabricated has a defect as detailed below.

5 [0007] As exemplarily depicted in Fig. 1, a self-shadowing phenomenon often results in the step of deposition of the CVD oxide film 35 due to an undesired anisotropic deposition, wherein the CVD oxide film 35 contains a void therein at the central portion of the shallow isolation trench 34 as viewed in the horizontal direction. If the void 36, as shown in Fig. 2, remains after the wet etching, the CVD polysilicon film 38 is received in the void 36 to form an undesired silicon region 39. The silicon region 39 may cause a short-circuit failure between gate electrodes, for example, in an interconnect pattern formed on the silicon region 39. In short, the STI technique may involve a short-circuit failure due to the void of the CVD oxide film 35 in the case of a finer pattern for the device elements.

20 [0008] A high density plasma CVD (HDP-CVD) technique is now expected to solve the above problem in the current STI technique by effecting simultaneous deposition and etching of the oxide film 35. The HOP-CVD technique generally uses a low-pressure plasma, wherein electron density is designed between about  $10^{12}$  and about  $10^{14}$  to increase the mean free path of electrons, while a bias voltage is applied to the substrate to further increase the vertical component of the mean free path of the electrons.

30 [0009] In this technique, a larger thickness of the deposited oxide film minus smaller thickness of the etched oxide film provides a moderate deposition of a resulting oxide film (hereinafter referred to as a bias oxide film) having a higher density than an ordinary CVD film, which is suitable for a shallow isolation trench having a smaller width. Inductive coupled plasma or electron cyclotron plasma may be used as the plasma source for the HDP-CVD process.

40 [0010] Although the proposed HDP-CVD technique provides a bias oxide film having a higher density which can be effectively deposited in an isolation trench having a high aspect ratio, a MOS device having the isolation trench thus formed sometime involves a defect wherein a current-voltage characteristic of MOS transistors varies.

### SUMMARY OF THE INVENTION

50 [0011] In view of the above, it is an object of the present invention to provide a method for manufacturing a semiconductor device including an isolation trench having a smaller width, by using an improved HDP-CVD process.

55 [0012] It is another object of the present invention to provide a semiconductor device having an improved isolation trench capable of suppressing variations in the current-voltage characteristics of transistors.

[0013] The present invention provides a method for

manufacturing a semiconductor device comprising the consecutive steps of etching a surface region of a silicon substrate to form an isolation trench, forming a thermal oxide film on an inner wall of the isolation trench, depositing a CVD oxide film at least on the thermal oxide film, depositing a bias oxide film overlying the silicon substrate including inside of the isolation trench by a high-density plasma CVD technique, removing a portion of at least the bias oxide film remaining above a specified level of the silicon substrate to leave the isolation trench filled with at least the bias oxide film, and forming a plurality of element regions separated by the isolation trench from one another.

**[0014]** The present invention also provides a semiconductor device comprising a silicon substrate having an isolation trench thereon, and a plurality of element regions isolated from one another by the isolation trench, the isolation trench including therein a thermal oxide film, CVD oxide film and a bias oxide film consecutively deposited from a bottom surface of the isolation trench, the bias oxide film having a higher density than the CVD oxide film.

**[0015]** In accordance with the semiconductor device of the present invention and the semiconductor device manufactured by the method of the present invention, the current-voltage characteristic of the transistor can be improved because the oxide film deposited by the CVD step before the HDP-CVD step protects the thermal oxide film which in turn protects the silicon surface during the HDP-CVD step, whereby the silicon surface is not exposed to and protected against the HDP.

**[0016]** The above and other objects, features and advantages of the present invention will be more apparent from the following description, referring to the accompanying drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

##### [0017]

Fig. 1 is a sectional view of a conventional semiconductor device having an isolation trench at a fabrication step thereof;

Fig. 2 is a sectional view of the semiconductor device of Fig. 1 at a following step;

Fig. 3 is a sectional view of another conventional semiconductor device manufactured by a HDP-CVD process;

Fig. 4 is a perspective view of the semiconductor device of Fig. 3 at a following step thereof;

Figs. 5A to 5D are sectional views of a semiconductor device at consecutive steps of a fabrication process thereof according to an embodiment of the present invention;

Figs. 6A to 6D are enlarged partial sectional views of the semiconductor device of Figs. 5A to 5D at specified steps; and

Figs. 7A and 7B are enlarged detailed sectional

views of the semiconductor device of Figs. 5A to 5D at specified steps.

#### PREFERRED EMBODIMENT OF THE INVENTION

**[0018]** Before describing an embodiment of the present invention, a defect caused in the conventional HDP-CVD technique will be described for a better understanding of the present invention.

**[0019]** Referring to Fig. 3, the HDP-CVD process includes the step of forming a pad silicon oxide film 32 and a mask silicon nitride film 33 consecutively on a silicon substrate 31, followed by formation of a photoresist pattern (not shown) on the mask nitride film 33. After selectively etching the pad oxide film 32 and the mask nitride film 33 by a dry etching using the photoresist pattern as a mask, an isolation trench 34 is formed on the silicon substrate 31 by a dry etching using the mask nitride film 33 as a mask. Subsequently, a thermal oxidation is performed to form a silicon oxide film 45 within the isolation trench 34, the thermal oxide film 45 extending from the edge of the pad oxide film 32 on top of the silicon substrate 31 to cover the side walls and the bottom wall of the isolation trench 34.

**[0020]** Thereafter, a bias CVD oxide ( $\text{SiO}_2$ ) film 44 is deposited by a HDP-CVD process over the entire surface including the inside of the isolation trench 34. In this HDP-CVD process, the bias oxide film 44 is deposited while the thermal oxide film 45 is etched. Especially, the thermal oxide film 45 is strongly attacked at the top corner region 43 of the isolation trench 34 during the HDP-CVD process, whereby a surface region of the silicon substrate 31 is exposed from the thermal oxide film 45 within the isolation trench 34 at the top corner region 43.

**[0021]** Referring to Fig. 4 showing the semiconductor device formed by using the HDP-CVD process, the semiconductor device includes a MOS transistor 46 having a gate 42 and source and drain electrodes 40 and 41 disposed in a spaced relationship with each other along the isolation trench 34. The isolation trench 34 has in the vicinity of the transistor 46 a location where the mask nitride film 33, the pad oxide film 32 and the bias oxide film 44 are etched back.

**[0022]** In the resulting MOS transistor 46, it is found that the transistor characteristic is damaged because of the variations in the gate voltage dependence of the drain current due to the exposed surface of the silicon substrate 31 at the top corner region 43 of the isolation trench 34. The present invention is devised for preventing the silicon surface from being exposed in the isolation trench, as detailed below.

**[0023]** Now the embodiment of the present invention is more specifically described with reference to the accompanying drawings. Referring to Fig. 5A showing a step of fabrication process of the present embodiment, a 200-angstrom-thick pad oxide film 12 and a 0.15-micrometer-thick mask nitride film 13 are consecutively

formed on a silicon substrate 11, followed by the step of formation of a photoresist pattern 19 on the mask nitride film 13. Subsequently the mask nitride film 13 and the pad oxide film 12 are subjected to a selective etching using the photoresist pattern 19 as a mask to expose a surface region of the silicon substrate 11. Further, the exposed region of the silicon substrate 11 is subjected to a dry etching to form an isolation trench 14 having a depth of 0.4  $\mu\text{m}$  and a width of 0.4  $\mu\text{m}$  or less. The detail of the films at this step is depicted in Fig. 6A, wherein the pad oxide film 12, the mask nitride film 13 and the photoresist pattern 19 define an edge substantially flush with the side wall of the isolation trench 14.

[0024] Thereafter, as shown in Fig. 6B, a 1000-angstrom-thick thermal oxide film 15 having an excellent coverage characteristic is formed on the surface of the isolation trench 14 at a temperature of 1100° C, for example. The thermal oxide film 15 extends from the cut edge of the pad oxide film 12 and covers the side walls and the bottom wall of the isolation trench 14. The thickness of the thermal oxide film 15 is preferably between 200 and 600 angstroms so as to effectively protect the silicon surface and not to form a bird's beak.

[0025] Subsequently, a thin CVD oxide film 16 is deposited on the entire surface of the wafer including the surfaces of the thermal oxide film 15 and the mask nitride film 13 by a LPCVD technique together with a temperature oxidation technique, as shown in Fig. 5B. Fig. 6C depicts the detail of the thin CVD oxide film 16, wherein the CVD oxide film 16 covers the entire surface of the wafer, covering directly the thermal oxide film 15 and the mask nitride film 13.

[0026] Further, a bias oxide film 17 is deposited in the isolation trench 14 and on other portion of the wafer by a HDP-CVD technique using a bias deposition system at a temperature between about 200 and about 400° C, and at a pressure between about 1 and about 10 mmTorr. In this step, the bias oxide film 17 is moderately deposited while the CVD oxide film 16 is substantially entirely removed by a low-pressure plasma etching, with an inclination angle being about 45° at the edge of the bias oxide film 17. The bias oxide film 17 is formed in the isolation trench 14 and on the mask nitride film 13 in the vicinity of the isolation trench 14. The inclination angle depends on the bias power, and is about 40° for 1500 watts of the bias power, about 45° for 3500 watts, and about 50° for 5000 watts. Thereafter, the bias oxide film 17 is subjected to a CMP (chemical-mechanical polishing) step to obtain a substantially planar surface for the bias oxide film 17, as shown in Fig. 5D, wherein element regions 20 for receiving therein MOS transistors are separated by the isolation trench 34..

[0027] Fig. 7A shows the detail of the semiconductor device at the step of Fig. 6D, wherein it is depicted that the CVD oxide film 16 is substantially entirely removed except for the bottom of the isolation trench 14, whereas the thermal oxide film 15 remains substantially as it is due to the protection by the CVD oxide film 16. The re-

maining thermal oxide film 15 effectively protects the silicon surface against the plasma damage during the HDP-CVD process.

[0028] The thickness of the CVD oxide film 16 as deposited is preferably between about 100 and about 600 angstroms, and more preferably between about 200 and about 400 angstroms. The CVD oxide film 16 having a thickness above 600 angstroms may cause a higher aspect ratio of the isolation trench to degrade the coverage of the bias oxide film 17, although the larger thickness provides a stronger protection of the thermal oxide film 15 and affords excellent characteristics for MOS transistors or gate oxide film thereof.

[0029] After the step of Fig. 7A, the mask nitride film 13 is etched by wet etching using heated phosphoric acid, and then the pad oxide film 12 is etched by wet etching using hydrogen fluoride, thereby obtaining the structure shown in Fig. 7B. In this structure, the isolation trench 14 of the semiconductor device includes therein the thermal oxide film 15, the CVD oxide film 16 and the bias oxide film 17 which are consecutively formed on the bottom surface of the isolation trench 14. The CVD oxide film 15 is generally removed by the HD-CVD process from the other portion of the isolation trench 14 such as the side walls thereof.

[0030] As described above, in the embodiment of the present invention, the HDP-CVD process provide a bias oxide film 17 having a higher density in the isolation trench 14 whereas the CVD oxide film 16 protects the thermal oxide film 15 to protect the silicon surface against the plasma damage by the HDP-CVD. By this technique, the HDP-CVD process does not degrade the transistor characteristic even in the case of an isolation trench having an aspect ratio as high as 1.5 or more. The process of the present embodiment can be applied to a semiconductor device of 0.25  $\mu\text{m}$  or 0.18  $\mu\text{m}$  design rule.

[0031] The CVD oxide film 16 provide another advantage of protection of the mask nitride film 13 against electrostatic absorption during transportation of the wafer effected at an intermediate step of the fabrication process. Generally, the wafers are transported by a carriage with the top surface of the wafer on the carriage, which causes an electrostatic absorption due to the electrostatic charge accumulated on the silicon nitride film during the transportation of the wafer, if the silicon nitride film is not covered by the CVD oxide film.

[0032] The method of the present invention can be applied to bipolar transistor device, flash memory, DRAM in addition to the MOS device.

[0033] Since the above embodiments are described only for examples, the present invention is not limited to the above embodiments and various modifications or alterations can be easily made therefrom by those skilled in the art without departing from the scope of the present invention.

**Claims**

1. A method for manufacturing a semiconductor device having an isolation trench (14) on a silicon substrate (11) for separation of device elements, characterized by forming a thermal oxide film (15), a CVD oxide film (16) and a bias oxide film (17) consecutively on an inner wall of said isolation trench (14), wherein said bias oxide film has a higher density than said CVD oxide film. 5  
10
2. The method as defined in claim 1, wherein said thermal oxide film (15) has a thickness between about 200 and about 600 angstroms. 15
3. The method as defined in claim 1 or 2, wherein said CVD oxide film (16) has a thickness between about 100 and about 600 angstroms.
4. The method as defined in one of claims 1 to 3 further comprising the step of heating said silicon substrate (11) to form a pad thermal oxide film (12) on said silicon substrate (11). 20
5. The method as defined in claim 4, wherein said CVD oxide film (15) extends from a cut edge of said pad thermal oxide film (12) at a top corner region of said isolation trench (14). 25
6. The method as defined in one of claims 1 to 5, wherein said films removing step includes a chemical-mechanical polishing and a wet etching. 30
7. A semiconductor device comprising a silicon substrate (11) having an isolation trench (14) thereon, and a plurality of element regions (20) isolated from one another by said isolation trench (14), wherein said isolation trench (14) includes therein a thermal oxide film (15), CVD oxide film (16) and a bias oxide film (17) consecutively disposed from a bottom surface of said isolation trench (14), and said bias oxide film (17) has a higher density than said CVD oxide film (16). 35  
40
8. The semiconductor device as defined in claim 7, wherein said isolation trench (14) has an aspect ratio of above about 1.5. 45
9. The semiconductor device as defined in claim 7 or 8, wherein said isolation trench (14) has a width of less than about 0.4  $\mu\text{m}$ . 50

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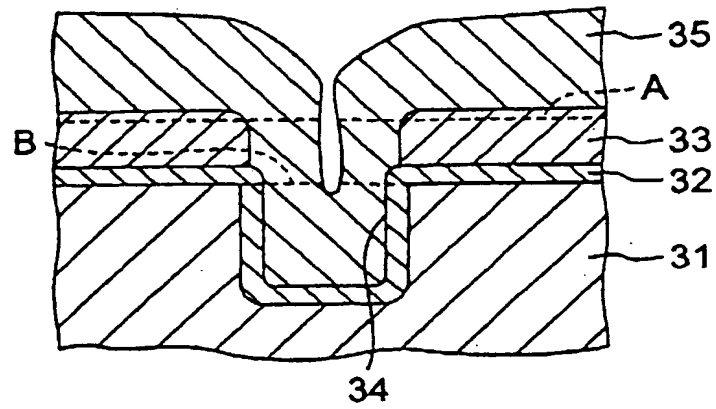


FIG. 1  
PRIOR ART

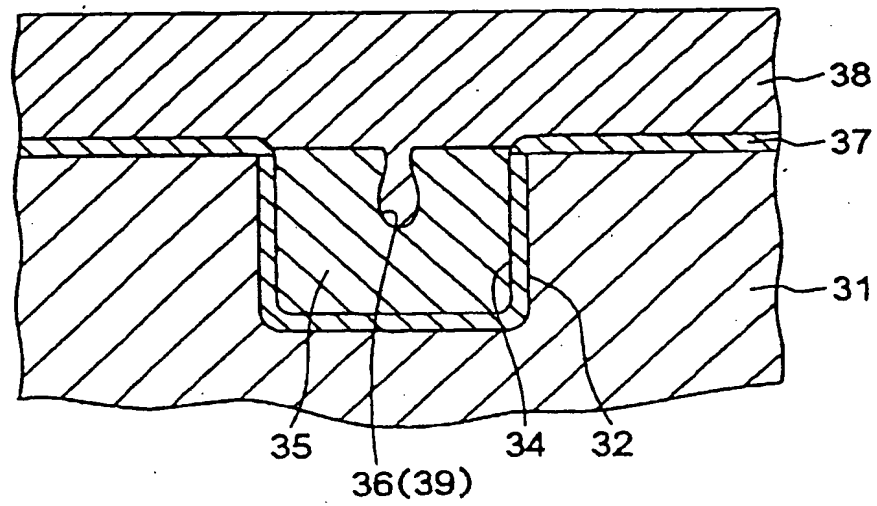


FIG. 2  
PRIOR ART

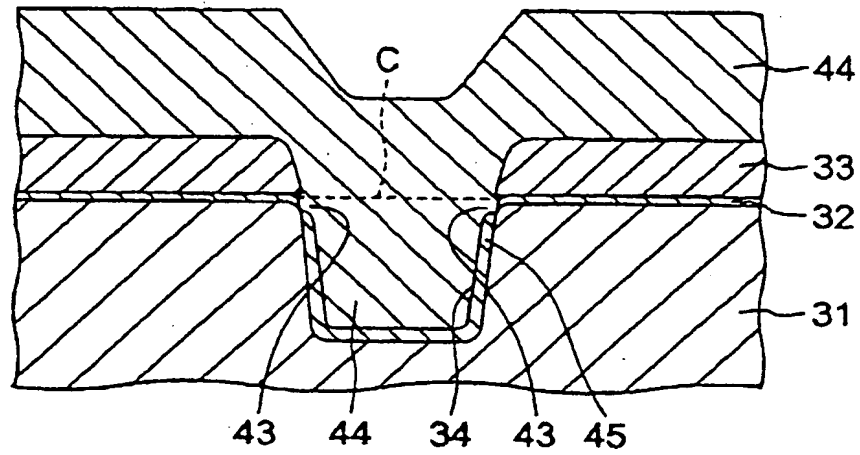


FIG. 3  
PRIOR ART

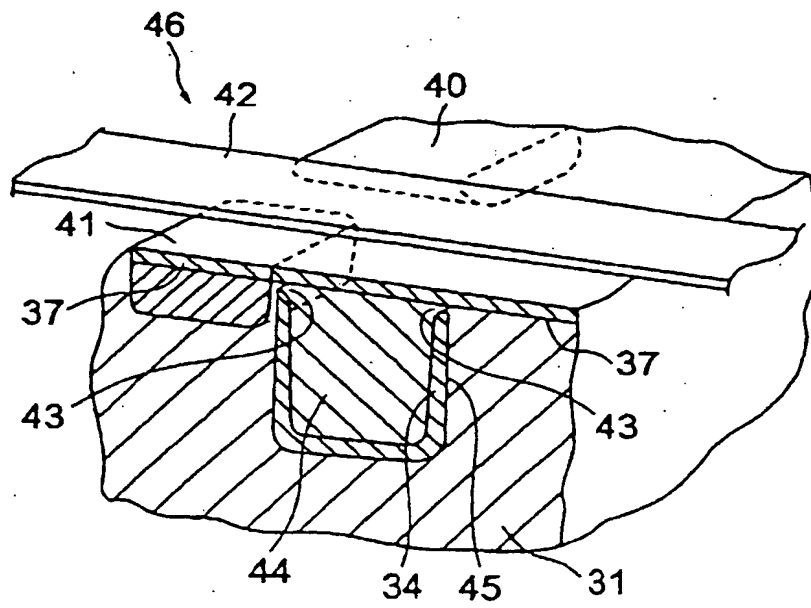


FIG. 4  
PRIOR ART

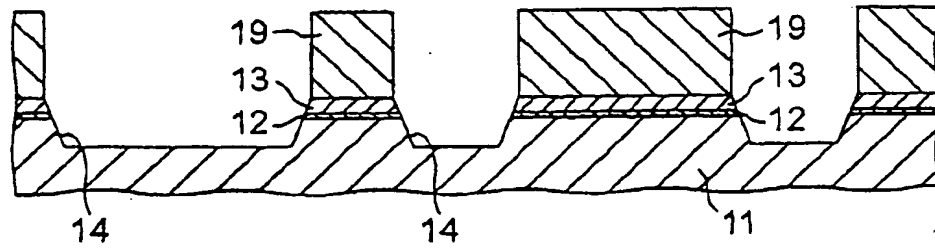


FIG. 5A

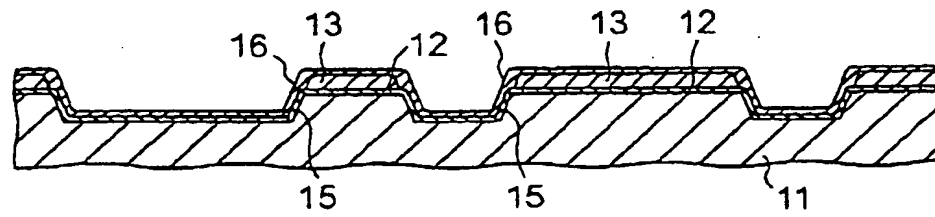


FIG. 5B

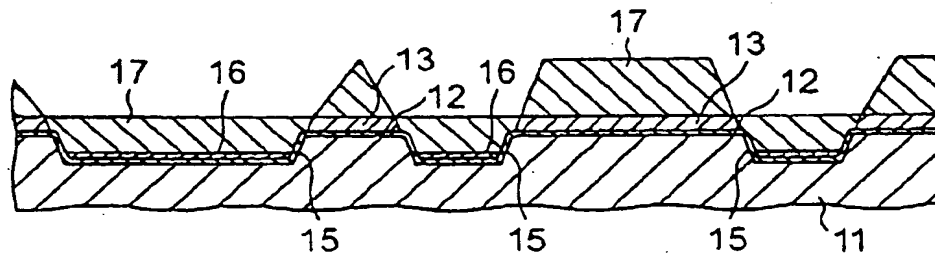


FIG. 5C

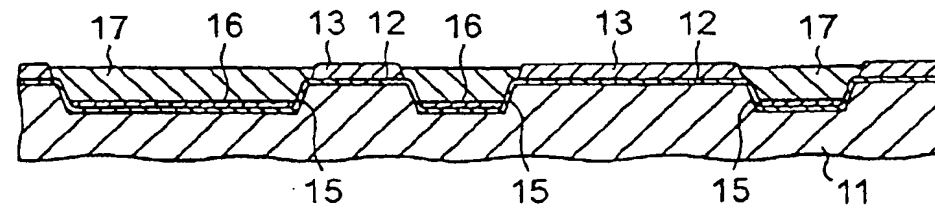


FIG. 5D



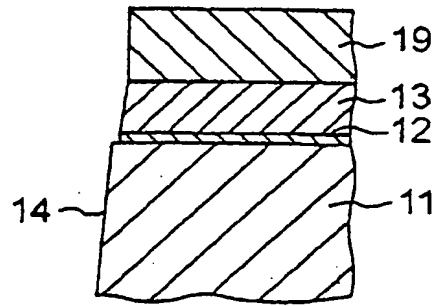


FIG. 6A

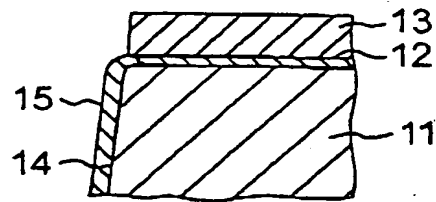


FIG. 6B

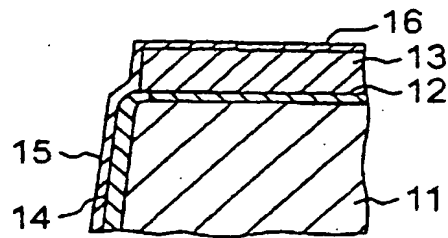


FIG. 6C

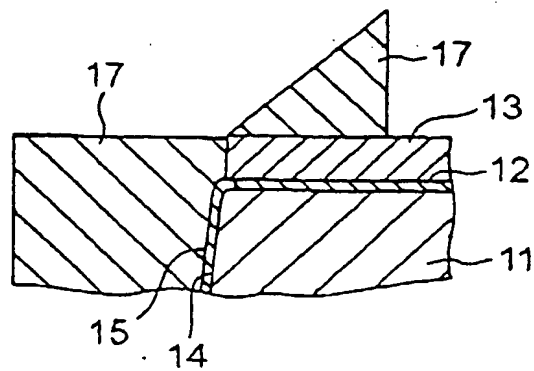


FIG. 6D

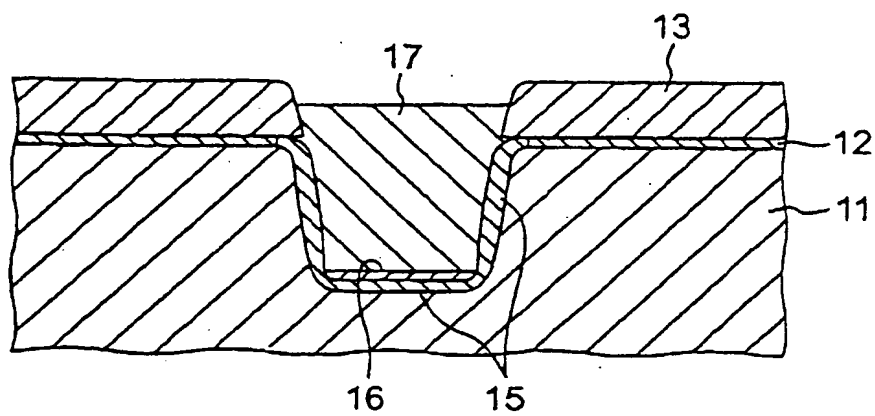


FIG. 7A

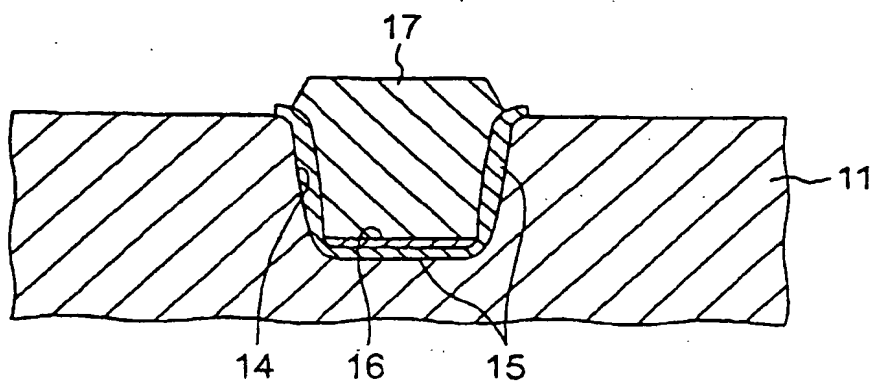


FIG. 7B



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# EUROPEAN SEARCH REPORT

Application Number  
EP 99 10 2632

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	NAG S ET AL.: "COMPARATIVE EVALUATION OF GAP-FILL DIELECTRICS IN SHALLOW TRENCH ISOLATION FROM SUB 0.25MUM TECHNOLOGIES." INTERNATIONAL ELECTRON DEVICES MEETING 1996. TECHNICAL DIGEST.IEDM, SAN FRANCISCO, DEC. 8 - 11, 1996, 8 December 1996, pages 841-844, XP000753846 INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS * page 841 * * page 842, right-hand column * * page 843, left-hand column; figures 5,6 * * page 843, right-hand column - page 844, left-hand column; figures 7-9; table 2 *	1-7	H01L21/762
Y	---	8,9	
Y	EP 0 813 240 A (TEXAS INSTRUMENTS INC) 17 December 1997 * column 1, line 26 - line 34 * * column 2, line 41 - column 4, line 46; figures 1A-1F,,2 *	8,9	
A	---	1-7	TECHNICAL FIELDS SEARCHED (Int.Cl.6) H01L
X	SHIOZAWA K ET AL: "ELECTRICAL CHARACTERISTICS OF ULTRA-FINE TRENCH ISOLATION FABRICATED BY A NEW TWO-STEP FILLING PROCESS" JAPANESE JOURNAL OF APPLIED PHYSICS, vol. 35, PART 2, no. 12B, 15 December 1996, pages L1625-L1627, XP000735146 * page L1625 - page L1626, left-hand column; figure 1 * * page 1627, left-hand column *	1,4,7-9	
A	---	2,6	
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The present search report has been drawn up for all claims			
Place of search BERLIN		Date of completion of the search 2 June 1999	Examiner Klopfenstein, P
CATEGORY OF CITED DOCUMENTS X: particularly relevant if taken alone Y: particularly relevant if combined with another document of the same category A: technological background O: non-written disclosure P: intermediate document		T: theory or principle underlying the invention E: earlier patent document, but published on, or after the filing date D: document cited in the application L: document cited for other reasons &: member of the same patent family, corresponding document	

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European Patent  
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# EUROPEAN SEARCH REPORT

Application Number  
EP 99 10 2632

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	<p>CHATTERJEE A ET AL: "A SHALLOW TRENCH ISOLATION USING LOCOS EDGE FOR PREVENTING CORNER EFFECTS FOR 0.25/0.18MUM CMOS TECHNOLOGIES AND BEYOND"</p> <p>INTERNATIONAL ELECTRON DEVICES MEETING 1996. TECHNICAL DIGEST.IEDM, SAN FRANCISCO, DEC. 8 - 11, 1996, 8 December 1996, pages 829-832, XP000753844</p> <p>INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS</p> <p>* page 829, left-hand column *</p> <p>* page 829, right-hand column, paragraph 11; figure 1 *</p> <p>* page 830, paragraph IV *</p> <p>-----</p>	1-4,6-9	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
The present search report has been drawn up for all claims			
Place of search		Date of completion of the search	Examiner
BERLIN		2 June 1999	Klopfenstein, P
<p>CATEGORY OF CITED DOCUMENTS</p> <p>X: particularly relevant if taken alone</p> <p>Y: particularly relevant if combined with another document of the same category</p> <p>A: technological background</p> <p>O: non-written disclosure</p> <p>P: intermediate document</p> <p>T: theory or principle underlying the invention</p> <p>E: earlier patent document, but published on, or after the filing date</p> <p>D: document cited in the application</p> <p>L: document cited for other reasons</p> <p>&amp;: member of the same patent family, corresponding document</p>			

See Form 1503 03/92 (P04C01)

